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Patents ADP number *(if you know it)*	
If the applicant is a corporate body, give the country/state of its incorporation	FINLAND 5911995004
4. Title of the invention	THE LPRF SYSTEM WITH FREQUENCY HOPPING EXTENSIONS
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	HELEN LOUISE HAWS NOKIA MOBILE PHONES PATENT DEPARTMENT ST GEORGES COURT ST GEORGES ROAD CAMBERLEY SURREY GU15 3QZ UK
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PAT 97321 GB

LPRF–FH: The LPRF system with frequency hopping extensions

Contents:

1 Abbreviations and Definitions

Abbreviation	Meaning
ACC	Associated Control Channel
BC	Broadcast
ChannelID	Channel Identification, a 4–bit field in the burst header identifying one of 16 possible channels
LPRF	Low Power RF
MAC	Medium Access Control
MU	LPRF Master Unit
RMAP	remote memory access protocol
SU	LPRF Slave Unit
T	LPRF symbol duration (1/812500 s)
t_{slot}	LPRF slot duration (10/13 ms)
TCH	traffic channel field of LPRF bursts (variable length)
EC	error correction
ED	error detection

2 Definitions

Term	Definition
Carrier	A carrier frequency used for communication
Channel	A TDMA channel. Bursts with a common ChannelID establish a TDMA channel on a selected carrier
downlink	direction from MU to SU
ED–message	a message that is sent over the ACC of the LPRF burst which is protected by low level error detection (ED) using a CRC
EC–message	a message that is sent over the ACC of the LPRF burst which is protected by low level error correction (EC) using a send & wait protocol
f–channel	a TDMA channel between MU and SU with fixed capacity
host unit	a communication device, that uses an LPRF MU for communication with other devices via LPRF SUs.
master unit	an LPRF interface that sets timing for an LPRF communication and can handle communication with several slave units. The master unit logically resides in a host unit and is controlled by the host unit.
passive slave unit	a slave unit that does not contain a transmitter but only a receiver. Thus, such a slave can only evaluate broadcast information.
slave unit	an LPRF interface that listens to LPRF MUs and can handle communication with only one MU at a time
sleep mode synchronous bursts	bursts that are sent regardless of whether the MU is in the sleeping state or active SUs that listen to these bursts do not need to change timing if the MU state changes

Term	Definition
uplink	direction from SU to MU
[illegible]annel	a TDMA channel between MU and SU with variable capacity allocated by the MU dynamically to the channel

3 References

|1| MC–link specification, Örjan Johansson, Anders Edlund, Ericsson, Nr.: TX/B 97: 0113, 15.10.97

|2| LPRF System Design Overview, Olaf Joeressen, NOKIA, Version 0.2 Ericsson and Intel

4 Introductory comments to LPRF–FH and this document

This document describes the LPRF system with frequency hopping modifications as needed to be permitted to raise the transmitter output power to above 0 dBm as required to achieve in house coverage for the HomeRF concept.

The basic approaches as required to handle the frequency hopping system are taken from |1|. Besides that the ideas of aligning timing to a host system (eg cellular system) to simplify the integration have been taken from the orignal LPRF system and are proposed in a form that fits the requirements of the frequency hopping approach.

In some sections parameter comparisons to |1| are made.

Changes to |2| are marked with revision bars.

This revisions assumes an air bit rate of 812.5 kbit/s. By using 1 MBit/s as in |1|, the link capacities can be scaled up accordingly.

CAUTION: In this document the terms LPRF and LPRF–FH are used equally, although the original LPRF system has significant differences to the proposed system.

5 LPRF overview

The LPRF system provides a fully digital link for communication between a master unit and one or more slave units. The system provides a radio link that offers a high degree of flexibility to support various applications and product scenarios.

Channels with a fixed known capacity and delay are provided between master and slave(s) (f–channels) as well as packet mode channels with variable delay and throughput (v–channels).

5.1 LPRF Major Features Summary

Table 1. Features summary

Parameter	Value	Comment
network topology	star	star configuration with one MU (eg a cellular phone) communicating with up to 31 SUs concurrently
coverage range	< 10 m < 100 m with PA	– even less acceptable – LOS range can be much larger
number of concurrent users (piconets)	$\geq$ 20	estimate, theoretically frequency division gives 79 users
link capacity	up to 2x339 kbit/s or 1x613 kbit/s	For these figures 100% of air time needs to be available for communication, ie no air time is blocked by interference from other systems or cellular transmission.
timing can be aligned to cellular system frame timing	must support GSM, PDC,D–AMPS + CDMA (IS–95)	multiples of the slot timing are equal to the respective cellular timing.
frequency band	2.4–2.5 GHz	ISM band, best choice with respect to to global usage and cost
multiplexing	frequency hopping spread spectrum + TDM	– hopping rate 1300 hops/s – complies with FCC and ETSI type approval regulations in the ISM band for power levels above 0 dBm
output power	0dBm or higher	0 dBm for low power devices, higher levels for HomeRF applications
link characteristics	variable rate, connection oriented and connectionless	from very low (vibra– or buzzer–slaves) to high (audio, data) data rates, either fixed capacity allocated or dynamically arbitrated by the MU
air interface timing	fixed slot timing, but configurable allocation of slots to channels	the allocations can be done such, that critical concurrent activities of LPRF and the host system are avoided (eg concurrent transmissions). This is facilitated to – support coexistence in a cellular host system – ease type approval – simplify RF design
native audio mode	A–law PCM transmission	other modes (eg CVSD coding as proposed in I1I) can be added but are not yet specified

Table 2. Summary of features that support independency of cellular standards

Host system property or integration issue	Supporting feature
not much power available	the system design permits that the LPRF MU enters a sleep mode to [illegible] power
close integration may lead to RF front end interference problems	The allocation of slots to channels can be done such that LPRF does not transmit concurrently with the cellular system. As a consequence, the burst length is variable as well as some timing parameters (frame length, sleep mode timing, etc.).
A SW oriented MU implementation has to coexist with the cellular DSP SW	The proposed approach prevents, that the SW has to manage two completely different time scales (frame timing, slot timing).
sudden slot changes	The LPRF SU is designed such, that a burst from the MU can be delayed significantly without loosing the connection. This effect was considered when determining the length of the synchronization preambles of the burst.

5.2 LPRF Network Topology and Channels

5.2.1 Network topology and MU–SU relation

LPRF uses a star topology for communication between an MU and several SUs. The MU sets all relevant air interface parameters such, that coexistence with the cellular phone is aided.

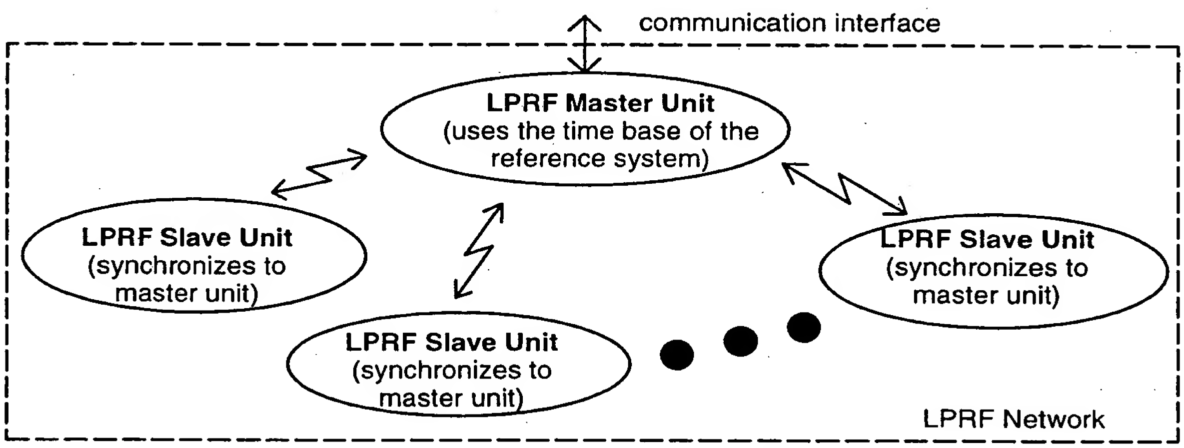


Figure 1. Basic LPRF Network Setup

As a consequence, an MU cannot generally at the same time function as an SU in another LPRF network since the other network may use a completely different frame timing. However, a unit can of course time multiplex its role in particular if it is in its sleep mode with respect to one of the two networks (cf |1|).

As far as the relation between MU an SUs are concerned, four different states are distinguished:

Table 3. MU–SU relation

Relation of SU to an MU	maximum number of concurrent SUs	Comment
[illegible]egistered	∞	The SU has not been registered to the MU and access permission for public services only.
registered	65535	The SU has access permission even to privileged services (such as initiating a phone call), but has no radio connection.
logged in	65535	The SU has contacted the MU recently. The SU is listens to MU broadcasting, but is not actively exchanging data and does not occupy a TDMA channel. The SU may be paged by the MU to initiate communication and vice versa.
active connection	15 + 16	The SU is logged on, is associated with a TDMA channel and can exchange data. – A single MU can handle at most 15 variable capacity and 16 fixed capacity channels concurrently.

With respect to all parameters given in Table 3, the actual MU implementation may be more restrictive than the LPRF air interface in general. Minimum requirements have not been specified so far.

5.3 LPRF radio burst structure and timing

5.3.1 Burst structure overview

The LPRF burst consists of three parts, as shown in Figure 2. The first part is the preamble which is used for symbol and burst synchronization. The second part is a header, that contains control information which is partly protected by forward error correction. In particular the header contains a 32–bit associated control channel used for internal signaling. The third part is the actual payload which is variable in length from 0 to 511 bytes and protected with a CRC. The CRC is not transmitted if the TCH is empty. Please refer to section 6.1 for more details on the contained fields.

Major features of this burst structure are

- preamble aids robust synchronization
- explicit channel ID permits flexible arbitration of data channels (no fixed air time allocation necessary)
- independent low level ARQ support for payload and control channel
- the control channel always available without stealing link capacity
- variable burst length
  –> avoids filling up frames with dummy data (power consumption!)
  –> eases future upgrades and changes
- payload can be reteievd even if header CRC fails (independent protection of TCHlength!)

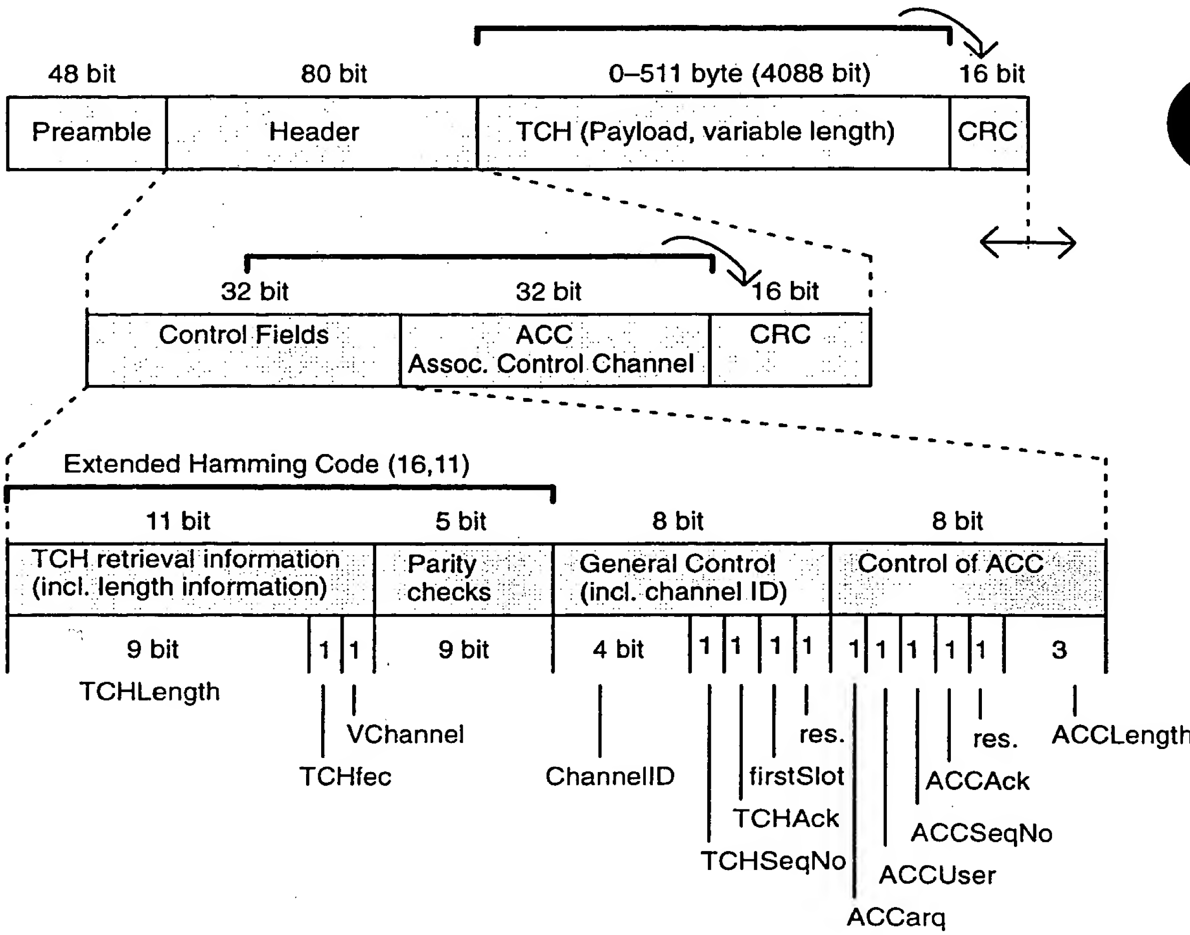


Figure 2. LPRF burst structure

5.3.2 LPRF timing

A major target in the design of the LPRF system was to make integration into a cellular phone as efficient as possible. It was thus decided that the timing of the LPRF air interface should satisfy the following constraints to ease coexistence of LPRF with a cellular phone transceiver and its activities:

1 The sleep mode of the air interface should be configurable to permit a common sleep mode timing for the cellular system and LPRF.

2 The timing of the LPRF system should be aligned to the cellular system timing to ease integration and type approval. The timing has to follow timing changes of the cellular system such as changing timing advance and slot changes in TDMA systems.

3 At least GSM, D–AMPS, PDC and CDMA (IS–95) need to be considered during the system design.

As a consequence the following features have been implemented:

- Although a fixed hopping rate (and slot timing) has been chosen, the number of slots that build a frame are kept programmable to aid coexistence with cellular systems. The slot length was chosen such that integer multiples result in frame lengths that equal those of the currently known cellular systems.
- All major remaining timing parameters, ie duplex timing, burst length and paging period are set by the MU for every connection (cf section 6.3).
- Significant spontaneous delays of MU burst transmissions, eg due to handover in the cellular system, are supported (they are called timing slips in LPRF)

Besides that, the LPRF system is a TDMA/TDD system.

5.3.2.1 Advantages of aligned timing

Timing alignment of sleep modes offers the following advantages

- the delay of incoming calls to the remote side can be minimized since a received cellular paging can within milliseconds be used to wake up remote units
- only one sleep mode needs to be handled in the phone (MU)

Timing alignment to cellular frames provides the following advantages

- concurrent transceiver activities can be avoided as needed to aid type approval and hardware design (eg RF shielding requirements)
- peak load of SW can be reduced by putting activities into non–overlapping periods
- HW interface can be shared

5.3.3 Slot and frame timing (active mode)

The system uses a fixed slot length of t_{slot}=10/13 ms. Thus 6 LPRF slots fit into a GSM frame (60/13 ms) and 26 LPRF slots fit into a PDC or D–AMPS frame (20ms). The slot length is slightly bigger than that proposed in |1| which leads to reduced overhead (assuming equal RF setup times). A single slot can carry at least 40 bytes of payload.

Frequency hopping is performed with every slot, thus the resulting hopping rate is 1300 hops/s. For handling of bursts that extend over several slots, the same rules as proposed in |1| are adopted.

No fixed guard times are needed to be specified since every burst carries length information. Thus shrinking the guard times (and thereby optimizing capacity) is possible in high performance systems based on compatibility information that the SUs provide. As well, the MU can multiplex connections such that guard speces on the MU side can be reduced while keeping the guard times for SUs as they are. This can lead to capacity increases of up to 50 % for single slot connections (see below)!

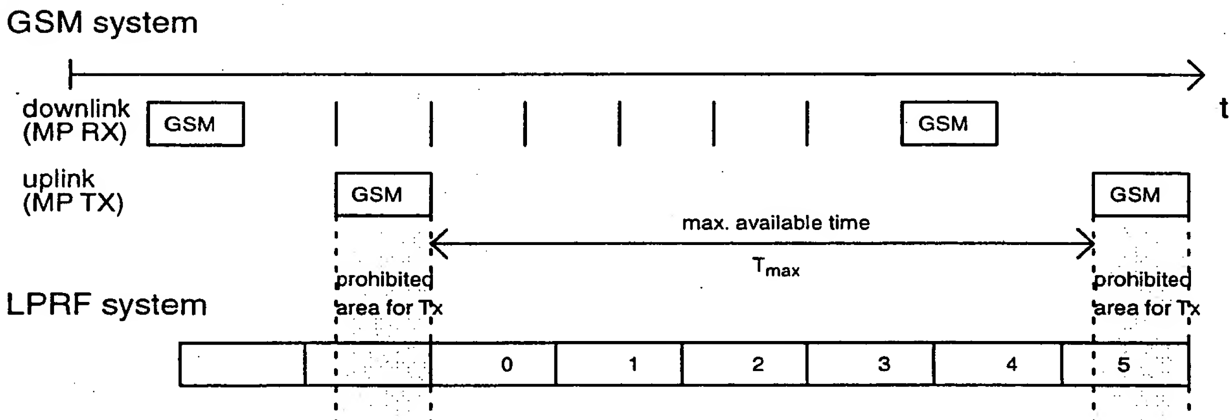
Normally, the transceiver activity starts at the beginning of a slot. However, slots can as well be marked as extension slots, which means that the slot is extended by 40 bytes. The subsequent slot can then no longer carry payload data (cf DMA and DHA packets in [1]) and the associated transceiver activity is delayed by 40 bytes (=40*8*T).

Whenever bursts extend over more than one slot, the whole burst is sent on the frequency of the first occupied slot.

5.3.4 Physical channel timing and allocation patterns

A master unit bundles an integer number of slots N_{Fr} to build a frame within which all activities are performed at fixed offsets relative to the frame start. Thus the total frame length is N_{Fr}*10/13 ms. To adapt to the timing of cellular systems typical choices for GSM are N_{Fr}=6 and for PDC and D–AMPS N_{Fr}=26. Multiples can as well be useful (eg for half–rate D–AMPS connections). Within the chosen frame, slots can be allocated to channels (ie connections between MU and SU) taking various constraints into account. This is configured using allocation tables.

It should be noted that the allocation as such does not require to transmit and receive over the full slot length if the payload size is temporarily smaller. Receiver and transmitter evaluate the payload length information and thus avoid transmission and reception of fill bytes.



D = dowlink
U = uplink
– = not allocated
x = extension slot

	0	1	2	3	4	5
1)	D	U	–	–	–	–
2)	D	U	–	D	U	–
3)	D	Dx	U	D	Dx	U

Figure 3. GSM channel timing examples single slot GSM connection

Figure 3 shows three examples of possible allocation tables for a GSM case with N_{Fr}=6 and without forward error correction.

Example 1): This channel allocation may be used to carry a 64 kbit stream in both directions (eg audio) which needs one slot in either direction per frame. The introduced delay equals the GSM frame timing.

Example 2): This allocation offers twice the capacity of example 1) and half the delay by allocation every third slot to a downlink or uplink frame.

Example 3): This would be a unidirectional high speed connection (eg for printing) extended double slots (downlink). This would provide a 1x547 kbit/s connection. Reception during cellular transmission needs to be possible in this case.

Table 4 summarizes the resulting channel capacities for single and multi–slots. The guard time for RF setup and uplink timing inaccuracy is 198 μs.

Table 4. Slot capacities (without FEC, at 812.5 kbit/s air bit rate)

Scenario	Max. payload per burst [bytes]	Capacity @ x–slot frame timing [kbit/s]				
		x=2	x=3	x=4	x=6 (GSM frame)	x=26 (PDC/ D–AMPS frame)
Single slot	40	208	–	–	69.33	16
Double slot	118	–	409	306	204.5	47.2
Double slot + 40 bytes extension	158	–	547	–	273	63.2
Triple slot	196	–	–	509	339	78.4
Triple slot + 40 bytes extension	236	–	–	613	409	94.4

5.3.5 MU active mode timing

All timing changes and allocations are made by the MU, while the SU has to be capable to deal with timing changes performed by the MU in the defined ways.

A typical case is that LPRF frames begin after a host system activity during which no LPRF air activity is permitted. Figure 4 shows an example for an MU that is hosted in a GSM telephone. LPRF transmission activities are not allowed during GSM transmissions, thus the LPRF frames follow directly after a transmit of a GSM packet.

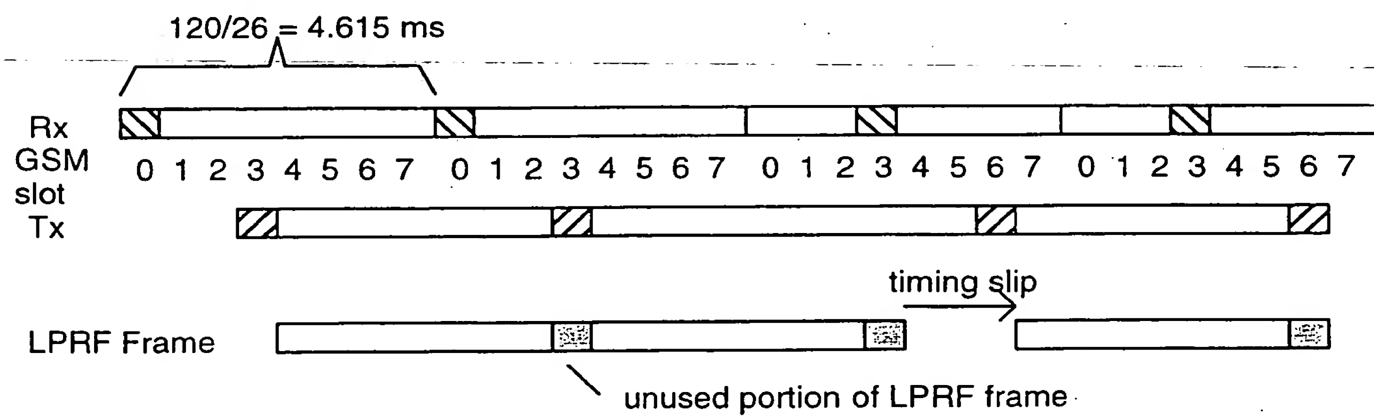


Figure 4. LPRF frame timing example in a GSM host telephone

In the example, the GSM phone is commanded to change communication from GSM time slot 0 to GSM time slot 3. The result is a frame timing slip of 3/8 LPRF frames. Note, that a period at the end of the LPRF frame is blocked by the GSM transmission, thus LPRF air time allocations cannot be made in this period.

As is apparent from the MU frame timing, the SU has to be able to cope with timing slips. Synchronizing activities to the cellular system is thus an MU problem only.

5.3.6 Handling of timing slips

Basically, timing slips will be restricted to multiples of the slot length and the MU schedules its frame start to the first slot after a blocked period. The freqency hopping pattern is kept unchanged and the frequency that is used in a slot does not change due to timing slips.

However, it is permitted as well to slowly adapt the underlying slot structure to follow timing changes due to timing advance and to optimize usage of the available air time.

5.3.7 MU sleep mode timing

An LPRF master may be quiet for a number of LPRF frames to save power during periods of inactivity of the host systems and the LPRF slaves. The master cannot maintain connections when entering the sleep mode, but still sends system information broadcast messages and listens at defined times for incoming access bursts from SUs.

LPRF sleep mode timing can be programmed to a large degree to make it possible to align the sleep mode timing to the sleep mode timing of the cellular system.

5.4 LPRF Channels

5.4.1 TDMA slots + physical channels

A channel between an MU and an SU uses downlink and uplink burst that are sent and received according to the parameters set by the MU.

An LPRF burst comprises two sub–channels and several flags. The first is the associated control channel (ACC) which is the primary communication channel for LPRF internal messaging between MU and SU (used eg for radio resource management and SU configuration). The second is the traffic channel (TCH) which is the primary communication channel for user traffic. Uplink and downlink capacity can be configured differently. The ACC capacity is 32 bit/frame and the TCH capacity can be up to 511 byte/frame. However, in practice timing and implementation constraints will usually lead to much smaller actual TCH capacities.

The control channel uses a simple send&wait ARQ protocol to protect traffic.

For the TCH optional error correction coding with a rate 2/3 code can be selected on a burst by burst basis.

For applications, two different kinds of connections are offered, v–channels and f–channels.

5.4.2 V–channels

V–channels are variable rate channels identified by a flag in the LPRF burst. They may have the same allocation table, providing an aggregate capacity that is shared between all active connections and arbitrated by the MU. One v–channel is reserved for broadcast applications and access procedures. Up to 15 v–channels can be used for different connections. The allocation of bursts to v–channels is done by the MU and the involved capacity and delay can vary considerably.

V–channels are best suited for data transfer, not for traffic exhibiting a fixed rate and requiring a limited delay like voice connections.

V–channels can be protected by the same simple send&wait ARQ protocol used on the associated control channel.

5.4.3 F–channels

Every f–channel has fixed allocation of air interface time per LPRF frame which is not used by any other channel. They thus have a fixed capacity always available to a connection as well as a known worst case delay.

On every f–channel, the ACC can be used as a separate control channel for applications as needed for display and keyboard I/O in wireless handsets. If higher capacity is needed (large displays, etc) a parallel v–channel can be opened or a special messaging format on f–channels be chosen.

6 LPRF Air Interface

6.1 LPRF radio burst

LPRF will pack the user data into a burst consisting of the following fields:

Table 5. LPRF Burst Structure

Field	Length [bits]	Comment
		Packet Synchronization
SynchHeader	32	Preamble for burst detection and timing synchronization MU: 0101 ... 0101, first sent bit is '0', SU uses the inverted MU sequence
UniqueWord	16	Used for determining the absolute timing of the burst. MU: 1110 1001 1001 1010, first sent bit is '1', SU uses the inverted MU sequence
		Medium Access Control Bits
TCHlength	9	Length of traffic channel field in bytes (0..511)
TCHfec	1	0 = no FEC on TCH 1 = r=2/3 FEC used
VChannel	1	0 = the burst belongs to a fixed capacity channel (f–connection) 1 = the burst belongs to a variable capacity channel (v–connection)
LengthCode	5	this field builds together with TCHlength,TCHfec and VChannel a (15,11) Hamming code with additional parity check , ie a (16,11) code
ChannelID	4	The number of the physical channel (TDMA channel!), the packet belongs to (0..15). Whether this is an f f– or v–channel depends on the VChannel flag.
TCHSeqNo	1	Sequence number for Send&Wait protocol of TCH data
TCHAck	1	Acknowledge for Send&Wait protocol of TCH data
FirstSlot	1	Identifies the first slot of an allocation pattern. This aids rapid reacqisition of the allocation patterns after timing slips.
reserved	1	reserved for future extensions
ACCarq	1	0 = only error detection on ACC, 1 = send&wait used on ACC
ACCUser	1	0 = ACC is LPRF internal control traffic, 1 = ACC is user traffic
ACCSeqNo	1	Sequence number for Send&Wait protocol of ACC data
ACCAck	1	Acknowledge for Send&Wait protocol of ACC data
reserved	1	reserved for future extensions
ACCLength	3	Length information for ACC, LPRF mode (ACCuser=0) – ACCLength specifies stealing capacity from TCH in 32–bit chunks in this mode if ACCLength>0 – up to 8*32 bit can be stolen from the TCH – the TCH does not carry any payload in this case – stealing is only permitted on v–channels User mode (ACCuser=1) – unit is bytes, only 0 .. 4 are valid settings

Table 5. LPRF Burst Structure (continued)

ACC	32	Associated Control Channel (ACC) data field. Used primarily to control and program the LPRF interface over–the–air and to transfer low rate user data.
HeaderCRC	16	Protection for LPRF header computed over the header from field ChannelID to field ACC (48 bits) (polynomial: $X^{16} + X^{12} + X^5 + 1$)
User Data Field		
TCH	TCHlength * 8	traffic channel field, used to transfer high rate user traffic (eg audio data)
TCHCRC	16	TCHCRC contains a CRC computed over the TCH with the same polynomial as the HeaderCRC

The header bits are aligned on 16–bit positions to ease a SW implementation. Major points with respect to the fixed length header are:

– 32 bit preamble and 16 bit unique word facilitate robust synchronization even if large timing slips occur

– The length information (TCHlength), TCH coding flag (TCHfec) and the v–channel flag (VChannel) are protected with a code (TCHlength+TCHfec-Flag+VChannel+LengthCode) that permits retrieving the traffic field (TCH) independently of the header CRC.

– ChannelID and VChannel are used to explicitly identify TDMA channels since timing as such is not sufficient for channel identification (timing slips!)

– An associated control channel (ACC) with 32 bit/frame gross capacity is provided. It is primarily used for LPRF internal signaling but can be used as well for user traffic in some cases.

Several parameters that influence the construction of the burst are negotiated during connection establishment. In particular:

– a maximum size of the TCH field is programmed separately for uplink and downlink (the corresponding maximum value of TCHlength depends as well on coding options). This corresponds to air time allocated by the MU.

– whether the send&wait protocol is used on the TCH is negotiated

– data formats to be used on the TCH are negotiated. Currently specified options are

  1 64 kbit/s a–law audio

  2 raw data

As is clear from the header, forward error correction can be added on a burst by burst basis as well as ARQ transmission.

No error correction is used on the header because the target worst case error rate of 10^{-3} is still leading to failing CRC only every 16'th burst. An unrecognizable failure of the code that protects the TCH information happens only once every several hours. If interference hits the burst, it has to hit directly after the unique word to affect the TCH information. otherwise, the burst is not received due to disturbed preamble anyway. This is considered sufficiently safe.

The data fields are sent LSB first.

6.1.1 Scrambling

Beginning after the unique word, the final burst is scrambled prior to transmission with a sequence generated in a linear feedback shift register with polynomial $x^9 + x^5 + 1$.

6.1.2 Encryption

The key stream generator is started newly for every frame based on the frame number. The key stream generator is started after the unique word, but encryption is only applied to the ACC if ACCUser=1 and the TCH, excluding the CRC and before forward error correction coding. LPRF internal control traffic is not encrypted.

6.2 Header and TCH error correction and error detection

LPRF uses the ACC for internal messaging. Two different approaches to protect messaging over the ACC are specified, error correction (EC) messaging and error detection (ED) messaging.

ED–messaging: ED stands for error detection. If a message is transferred in this mode, the header CRC (16–bit) is used to check the integrity of the message. If the CRC fails, the message is lost. The header flag ACCarq equals 0 in this case.

EC–messaging: EC stands for error correction. A simple send&wait ARQ protocol is applied in this case. It uses the one–bit sequence number ACCSeqNo and an acknowledge field (ACCAck). The header CRC is used to decide on the necessity of retransmissions. The same protocol can be used for messaging on the TCH if a channel is configured accordingly. In this case, TCHSeqNo, TCHAck and TCHCRC are used to control retransmissions.

6.2.1 ACC/TCH transmission send&wait protocol

To achieve maximum simplicity, a simple send and wait ARQ protocol is used. The description given below for ACCSeqNo and ACCAck is identically applied to TCHSeqNo and TCHAck if error correction is configured for the TCH.

The rules are:

1. The initialization values for ACCSeqNo and ACCack on a newly installed physical channel are: ACCSeqNo=1 and ACCack=0.
2. Every correctly received EC–message is acknowledged by the receiving party in the next burst that is sent by repeating ACCseqNo in the field ACCack. ACCack is **ONLY** changed if a EC–message is received without CRC failure.
3. The *transmitting party* deletes its EC–message from the message buffer after the message was acknowledged and inverts ACCseqNo. The message is repeated until it is acknowledged except the trans-

mitting party flushes the data in favour of new data. The ACCSeqNo is not changed in this case and the sender has to consider that changing the data is only safe if the last received burst had no CRC failure, because the receiver may have acknowledged the reception in the last (corrupted) frame.

6.2.2 Coding for the TCH receive information

Since too many traffic fields would be lost if the traffic field is discarded every time the header CRC fails, additional protection for the TCHlength field, TCHfec flag and the V–channel bit is used to enable retrieving the TCH even if the header CRC failed.

For the header that contains 80 bits including the CRC and at a link error rate of 10^{-3}, every $1/(1-(1-0.001)^{80})=13$'th burst the header CRC fails. However, only in one of 67 bursts the length field is actually corrupted. Additional error correction coding is thus used for the length field in order to enable retrieval of the TCH field even in the case of a header CRC failure. In turn the CRC protection of the first two header bytes is disabled which improves the rate of header CRC failures to every $1/(1-(1-0.001)^{64})=16$'th burst.

A protection with a (15,11) Hamming code and an additional even parity check is used. This permits correction of single errors and detection of 2 errors in the code word. The 11 bits are composed out of the 9 TCHlength bits, the TCHfec flag and the V–channel bit.

For an error rate of $P_e=10^{-3}$ and random errors, we obtain the following probabilities for E errors in the 16 bits of the coded length field:

$P(E=0)$	$= (1-P_e)^{16}$	$= .9841$
$P(E=1)$	$= 16\ P_e\ (1-P_e)^{15}$	$= 1.576*10^{-2}$
$P(E=2)$	$= (16*15/2)\ P_e^2\ (1-P_e)^{14}$	$= 1.183*10^{-4}$
$P(E>2)$	$= 1-P(E=0)-P(E=1)-P(E=2)$	$= .5546*10^{-6}$

Using single error correction

1. every $1/P(E=2)=8450$'th burst is lost due to a recognized corruption of the TCHlength field (ie every 39 seconds with GSM frame timing)
2. every $1/(P(E>2)=1.8*10^6$'th burst, a corrupted TCHlength field is not detected by the code because the errors produced a valid code word (ie. every 2.3 hours with GSM frame timing)

By further plausibility checking on the computed TCHlength value, the second case can be made even more seldom.

Further protection is not applied since an interferer would have to hit directly after the unique word to destroy data with a burst error although the burst is received.

6.2.3 TCH forward error correction

The (16,11) code that is used for protection of the TCH retrieval information is shortened to (15,10) and used for r=2/3 forward error correction code if the header flag TCHfec equals 1.

The length field TCHlength always counts actual traffic not coded traffic. If the last word of the (15,10) code is incompletely filled with data, the missing data is completed with 0 bits. Thus the effective number of bits transferred in this case is $\lceil TCHlength*8/10 \rceil*15$ bits.

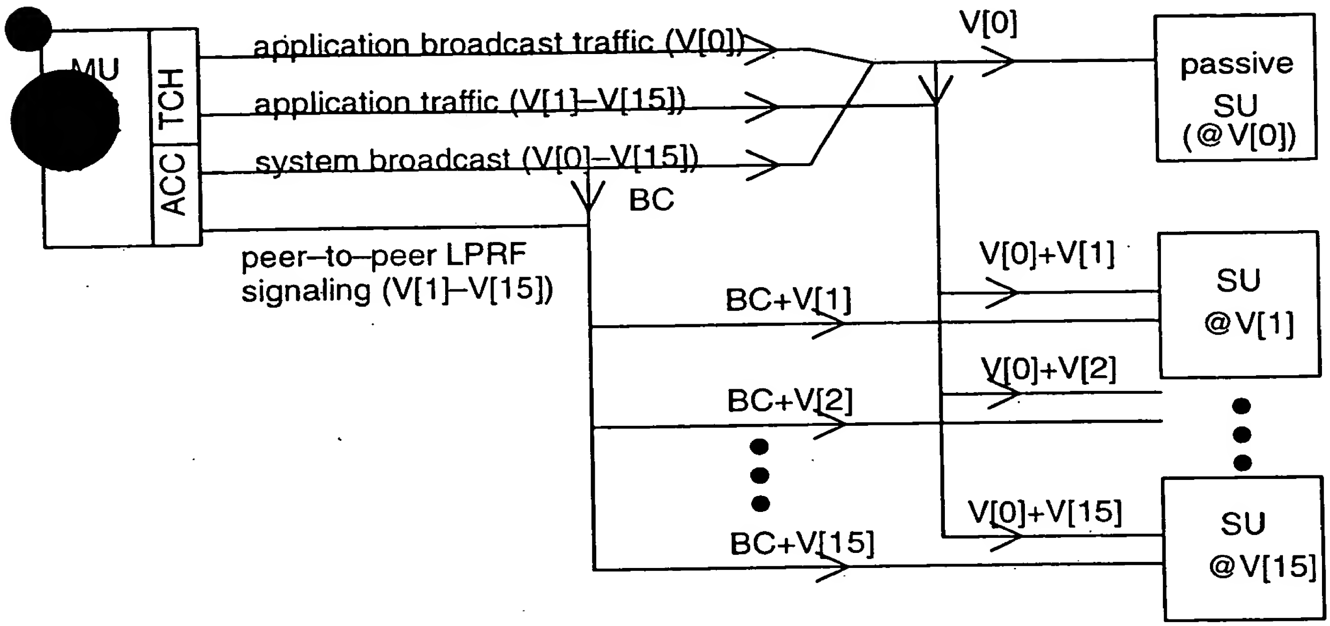


Figure 7. V–channel downlink structure (MU –> SU)

Figure 7 depicts the downlink channel structure for v–channels. The key properties are:

- the downlink TCH of V[0] carries user level broadcasting for all listening devices (even passive SUs).
- LPRF system broadcasting is done at least on the first slot of the allocation pattern, on sleep mode synchronous bursts and on V[0]. **The channel identification does not matter with respect to system broadcast messages.**
- non–broadcast ACC messages are addressed to a certain SU by means of the channel identification.
- The TCH traffic is as well addressed to a certain SU by means of the channel identification, information that is broadcasted on the TCH of V[0] can be used by all SUs.

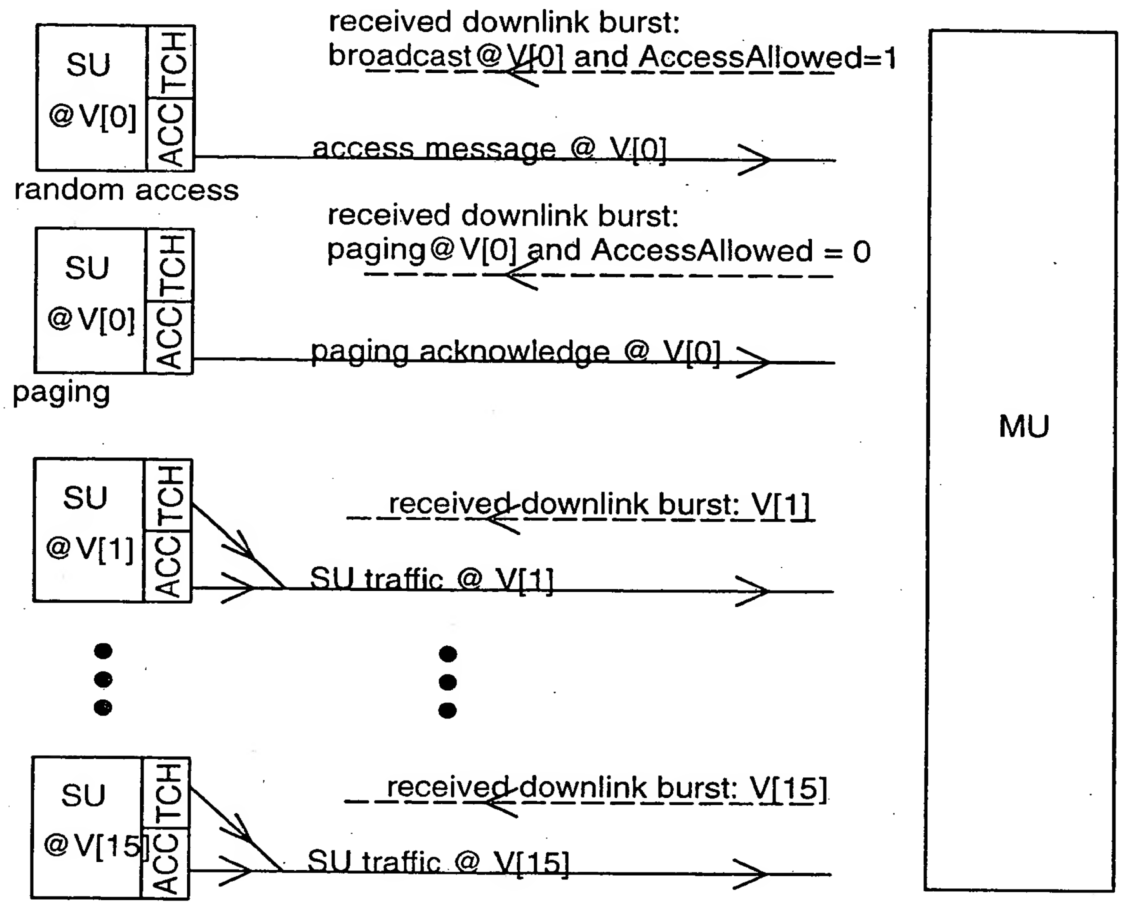


Figure 8. V–channel uplink structure (SU –> MU)

Figure 8 depicts the uplink channel structure for v–channels. The dashed lines indicate information from the received downlink burst in the same frame. The key properties are:

- uplink TCH and ACC are explicitly arbitrated by the MU. The MU achieves this by setting the channel identification in the downlink burst. The SU that is associated with this channel is allowed to respond in the uplink burst. The received downlink information is shown in Figure 7 with the dashed line.
- the downlink of V[0] is reserved for broadcast messages.
- the uplink of V[0] is reserved for access messages, if the broadcast bit AccessAllowed equals 1 (cf section 6.8.1).
- if AccessAllowed equals 0, the MU either does not attempt to receive any traffic in the uplink slot to save power, or waits for defined messages from the SU in some protocol procedures.

6.4.3 F–channels (fixed capacity)

F–channels are channels with a fixed allocated capacity. They are identified by setting the VChannel header field in the LPRF bursts to 0. The ChannelID field is used to distinguish 16 f–channels. Below we use the abbreviation F[x] for the f–channel with ChannelID=x. The MU allocates fixed air time to an f–channel for up– and downlink. Thus, the capacity is always available for communication and no further arbitration is done by the MU. F–channels are thus better suited if fixed delays are required for the channel. They are intended to be used primarily for transmission of fixed rate data streams, eg audio channels that cannot tolerate delay due to arbitration.

SUs that do not need f–channels do not need to support them.

In contrast to v–channels, for which no user traffic is permitted on the ACC, the ACC can be used as a control channel. A typical case for the use of an f–channel is an SU that is a cordless handset with audio, keyboard and display. This channel would carry for example A–law PCM on the TCH in both directions and exchange control messages over the ACC. If the capacity of the ACC is insufficient, a parallel v–channel can be used for control messaging at the price of higher air interface activity (ie power consumption)

6.4.4 Typical channel setup scenarios

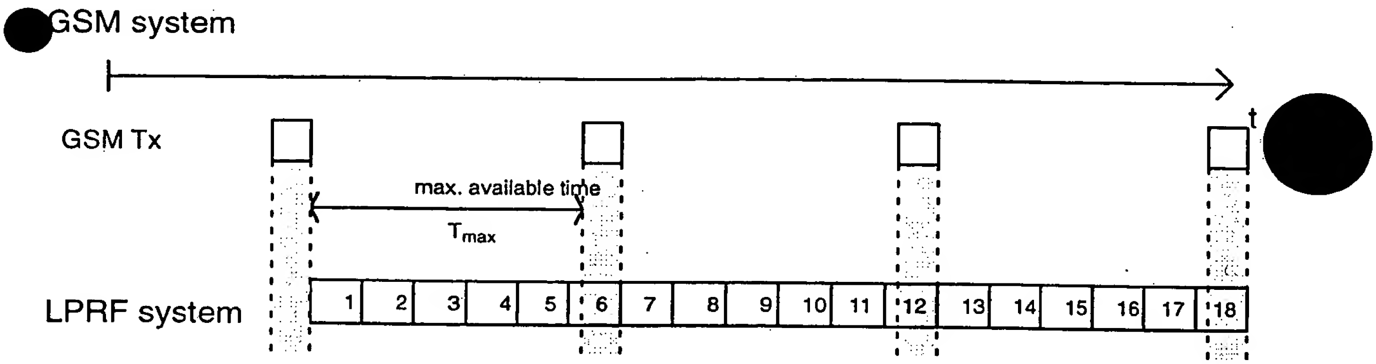
The LPRF system can be used in different cellular TDMA environments. The main representatives for cellular systems are GSM, CDMA and PDC/D–AMPS, the latter two having the same frame timing.

It is assumed below, that one f–channel for audio transmission (64 kbps A–law PCM) a slow v–channel V[0] and a higher throughput v–channel V[1] is handled.

Note that these scenarios are given under the assumption that the host unit aligns the LPRF timing to that of the cellular host system and that the mobile transmit time is prohibited for LPRF activities. This is not an LPRF requirement but it is assumed that host units can benefit from aligning the LPRF timing such.

6.4.4.1 GSM scenario

The cellular burst consumes 1/8 th of the cellular frame. Allocation patterns span over 3 GSM frames or 18 LPRF slots respectively. This permits aligning V[0] to GSM cellular sleep modes which span over multiples of GSM 51 mutilframes.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
V[0]:	D	U	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
V[1]:	D	U	–	–	–	–	D	U	–	–	–	–	D	U	–	–	–	–
F[0]:	–	–	D	U	–	–	–	–	D	U	–	–	–	–	D	U	–	–

D = downlink slot
U = uplink slot
– = not allocated for this connection

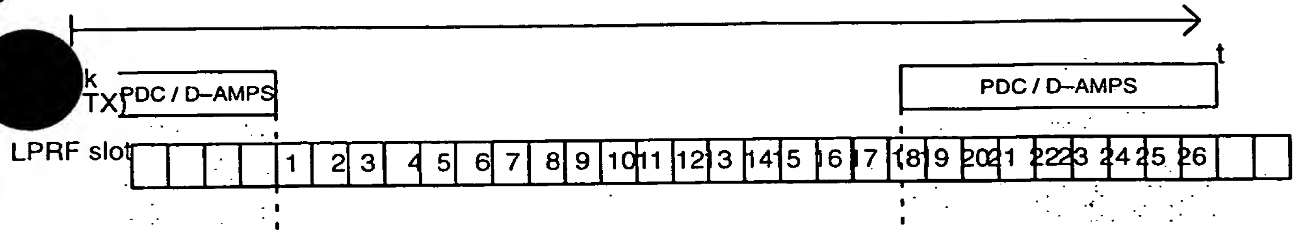
Figure 9. GSM timing example for single slot GSM connection

Clearly, V[0] has only one third of the capacity of V[1], which has identical capacity as F[0], ie 64 kbit/s in both duplex directions. The delay of the audio connection using F[0] is 6 slots or 4.61 ms.

6.4.4.2 PDC / D–AMPS scenario

The cellular burst consumes 1/3 rd of the cellular frame. Frame timing is 20 ms. With the given capacity of slots, 4 slot pairs are needed for the audio connection (or two double slot pairs). The solution with 4 slot pairs provides better delay and is assumed below.

PDC / D–AMPS system




```
V[0]   – –  D – U  – – – –  – –  – – – –  – – –  – – –  – –  – – –
V[1]   – –  D D U  D D U –  – –  – D D U  – – –  – – –  – –  – – –
F[0]   D U  – – –  – – – D  D U  U – – –  D U –  – – –  – –  – – –
```

D = downlink slot
U = uplink slot
– = not allocated for this connection

Figure 10. PDC/D–AMPS timing example

V[0] has very limited capcity, while V[1] is assymetric with double slots for downlink and thus provides 141 kbit/s for downlinks and 48 kbit/s for uplinks. F[0] carried a 64 kbit/s audio stream and is allocated such that the delay is minimized (delay is 11 slots = 8.46 ms). A mix of double and single slots is used to optimize power consumption (the double slot is not used completely !)

6.5 Access Identities and Registration

Any LPRF device has two preprogrammed identities used to manage access, authentication and encryption.

Table 6. LPRF device identities

Field Name	Description	Size
EQI	equipment identity, factory programmed unique serial number, only used for security procedures (secret identity)	64 b
MUaccessI	MU access identity, standard IEEE 802–1990 address (public identity)	48 b

Since encryption and authentication is still in the specification phase, the length of EQI is not finally decided. The EQI is usually not transferred over the air. It's role is the secret component of security procedures. However, if an SU is registered to an MU (eg a phone) by putting both sides into a special registration mode, the EQI is transferred from SU to MU and stored in the MU as input to security algorithms in future communication requests (see below).

During registration, various other information is exchanged (cf section 6.10.3) in particular a 16–bit registration number (RegNum) identifying this particular SU–

MU association and the MU access identity, which is stored in the SU to facilitate searching and connecting to a certain MU.

The MU access identity is broadcasted by the MU, to avoid that an SU has to inquire to an MU which the SU has not registered to anyway.

6.6 Security Architecture

CAUTION: *The security approaches are currently being reworked, especially with respect to the involved algorithms and necessary wordlengths.*

To aid security in the LPRF system, every LPRF interface (SUs and MUs) will be programmed in the factory with a unique equipment identity (EQI) that is the secret identity in cryptographic algorithms. Only during SU registration, the MU can read the EQI of the SU. Thus, the EQI of the slave can be used later on as a secret key serving encryption and authentication procedures between MU and SU without sending this key over the air interface.

Based on this key modern encryption and authentication approaches as applied in GSM and DECT can be implemented.

The following security services have been specified so far:

- SU authentication (MU validates access rights)
- session key setting

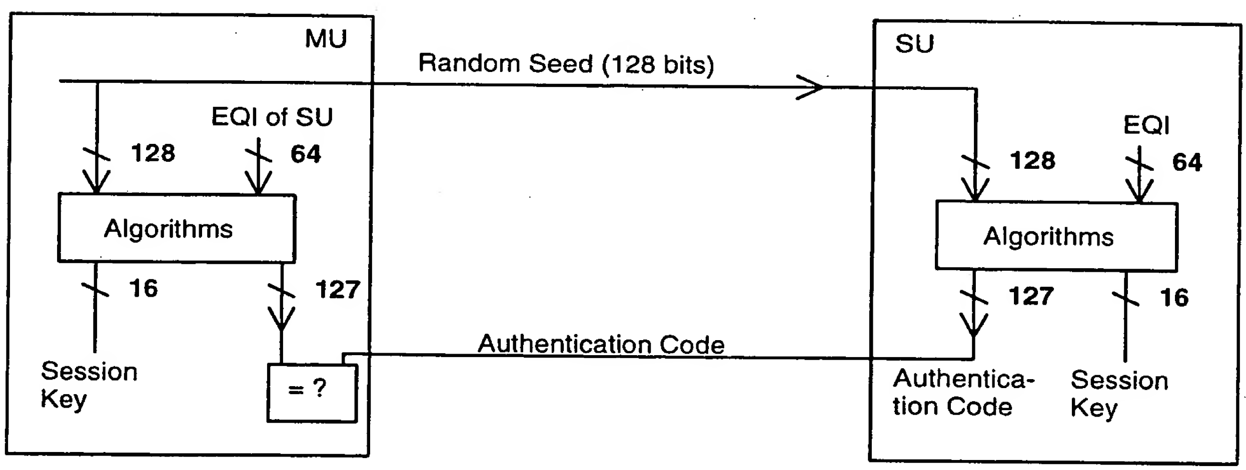


Figure 11. Security Architecture

6.6.1 Registration

Since LPRF will not require using separate security modules (eg a SIM card) it is necessary to tell the MU about the secret identity of the SU (the EQI). As in current cordless systems (eg DECT) the EQI is thus planned to be sent over the air from SU to MU which is a potential security problem.

The following countermeasures are implemented to reduce the probability of this event and thus the probability of eavesdropping:

1. The SU permits reading the EQI only if the SU is manually set into a special registration mode by some user activity
2. The MU accepts new registration only if the MU is manually set into a special registration mode by some user activity

Thus, registration is only possible if the user puts both devices manually into special modes. It is assumed that this is done in a safe environment and seldomly.

6.6.2 Authentication

The MU can at any time request authentication by sending an authentication command with a 128–bit random seed as parameter. The SU computes a 127–bit authentication code from the random seed and its own EQI. The MU performs the same computation and compares the resulting values. Equality means that the authentication succeeded.

6.6.3 Encryption

When applying basic encryption to channels, the MU scrambles user data (ACC in user mode and TCH) with a sequence generated in a linear feedback shift register without regarding the underlying message structure. The 16–bit start value is derived from session key and frame number. The key is computed from a 128–bit random seed that is provided by the MU.

6.7 LPRF internal messaging formats

To be able to maximize the throughput on the ACC without compromising with respect to flexibility, 4 formats are used which differ with respect to the number of different messages and the size of the associated data field.

Table 7. Message formats for LPRF control messages on the ACC bits

<table>
<tr><th>ACC–Bit</th><th>M28</th><th>M24</th><th>F24</th><th>F16</th></tr>
<tr><td>24–31</td><td rowspan="7">28 bit data</td><td rowspan="3">24 bit data</td><td rowspan="3">24 bit data</td><td rowspan="2">16 bit data</td></tr>
<tr><td>16–23</td></tr>
<tr><td>8–15</td><td rowspan="6">13 bits message number or address</td></tr>
<tr><td>7</td><td rowspan="7">7 bits message number</td><td rowspan="5">5 bits message number or address</td></tr>
<tr><td>6</td></tr>
<tr><td>5</td></tr>
<tr><td>4</td></tr>
<tr><td>3</td><td rowspan="3">3 bits message number</td></tr>
<tr><td>2</td><td colspan="2">RWI</td></tr>
<tr><td>1</td><td>1</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td colspan="2">0</td></tr>
</table>

These formats apply if the ACC control field identifies the message as an LPRF internal message (ACCUser=0). When mapping information items into the ACC, the information is always sent LSB first. User traffic (ACCUser=1) may use the ACC in any format.

M28 messages are mainly used for LPRF system broadcasting (MU–>SU) since capacity is critical if the MU is sleeping and sends only few packets.

M24 messages are used in some protocol procedures for throughput critical messaging from SU to MU,

F24 and F16 messages are used to program parameters from MU to SU or for example to retrieve information needed for negotiation of parameters using virtual memory read/write as specified by RMAP messaging (see below)

6.7.1 RMAP messaging

To simplify the handling in the SU, most communication is performed by the MU by writing/reading to/from virtual memory locations of the SU. This is done using the remote memory access protocol (RMAP).

While the M28 and M24 messages are dedicated messages to be sent from MU to SU or vice versa, F24 and F16 messages contain a field (RWI) that permits sending data from MU to SU as well as retrieving data from the SU. For F24 and F16 messages, the message number is thus treated as an address and the underlying mode is a memory in the SU that is written to or read. However, at least for the write messages, the address could as well be interpreted as a message number.

It is intended to exchange most information between master and slave using the remote slave memory access. This access is only available if a slave has connected to a master on a dedicated physical channel. This does not imply that the slave has been granted access (for user traffic) by the master already. The master may only have opened a physical channel to be able to determine if this slave's connection request can be served or has to be refused.

RMAP uses messages in the F24 or F16 format. They can be transferred as ED– or EC–messages depending on the purpose. The RWI field is used as follows:

Table 8. Meaning of the RWI field

Field	Direction	Value	function
RWI	MU–>SU	0	write to slave memory / message
	MU–>SU	1	read request to slave
	SU–>MU	0	slave memory lookup
	SU–>MU	1	interrupt / message

The following activities are possible using the RMAP message format:

Write (Master–>Slave): The master writes a 16–bit word to the defined slave memory address. The activity is protected by the EC–message transmission protocol.

Read (Master–>Slave): The master requests a read to the designated slave memory address. The content of the data field is ignored by the slave. The slave responds to the read command by sending a memory lookup with the requested address.

Slave Memory Lookup (Slave–>Master): The slave sends the content read from the indicated slave address to the master. This happens in response to a read from the master unit to complete the masters read operation. The slave is as well allowed to respond to write messages with a memory lookup to acknowledge the write operation, if the messaging channel is not used by other traffic.

Interrupt (Slave–>Master): The slave may send an interrupt message to the master if an activity of the master has to be initiated by the slave. The address field identifies different interrupts, while the data field may carry side information for this interrupt.

Together with a memory map of an LPRF slave and within the functionality visible in the memory map, the master has full control of the slave.

The size of the fields is given either in bytes (B) or bits (b). Time values are given in multiples of the LPRF symbol rate (T) if not defined otherwise. The tables contain two address fields. One for F16 access and the other for F24 access.

6.8 LPRF system broadcasting (M28 messages)

LPRF system broadcasting is done to inform SUs about various parameters that the SU needs to know to be able to contact the MU and to manage ca changes, etc. This kind of broadcasting uses special messages that are s the v–channel downlink ACC.

M28 messages contain 28 bits of data and are optimized for throughput since the ACC capacity is quite small in some system modes, particularly if the MU is sleeping. In particular, sleep mode synchronous bursts (from MU to SU) always contain a M28 message. They are primarily used in the MU for system broadcasting.

6.8.1 System broadcast information overview

Table 9 describes the meaning of the different message fields that are contained in the different M28 messages.

Table 9. Information items to be distributed using LPRF system broadcasting

Information item	size (bit)	comment
MU status information (BCS information), sent in every BC burst		
AccessAllowed	1	AccessAllowed = '0': no uplink allowed AccessAllowed = '1': an access message is allowed to be sent after any received v–channel burst with ChannelID=0
SleepBurst	1	informs SUs that a sleep mode synchronous burst is sent if set to 1
SleepMode	1	informs the SUs that the master is currently in the sleep mode if set to 1
Access information (BCA information), sent every 3'rd BC burst		
BCSeqNo	2	sequence number of broadcasting changes if BC information changes, to ensure that the SUs can derive always a consistent set of parameters. The value 0 can be used when broadcasting a default parameter set by the MU (which then eases synchronizing to the MU). Thus only 1,2,3 should be used if no default parameter set is used.
MUaccesl(31:0)	32	The part of MUaccessI is broadcasted to permit identification of the MU without connecting to. Cf Table 6.
N_{down}	4	offset of V[0] downlink within chosen frame
N_{TDD}	3	duplex timing for V[0] in number of slots actual duplex timing is $N_{TDD}*t_{slot}$ + extension time (see below)
ExtDuplex	1	duplex extension flag 0 = do not add extension time to duplex timing 1 = add extension time to duplex spacing (40*8*T)
N_{Fr}	7	frame timing in multiples of the slot length t_{slot} (10/13 ms), permits up to 98 ms
SleepFrames	10	sleep mode factor for frame timing sleep timing = SleepFrames*t_{slot}*N_{Fr} (10 bit allow up to 4.73 s @ GSM frames: 4.61 ms)
Auxiliary information (BCX information), sent if neccessary		

Table 9. Information items to be distributed using LPRF system broadcasting (continued)

[illegible]rmation [illegible]em	size (bit)	comment
[illegible]ime	26	Current value of LPRF MU slot counter, needed to synchronize multiframe counter and hopping frequency generator
MAC (BCM information), sent if neccessary, prioritized		
Data	20	Information depending on the MsgNo
MsgNo	3–4	Number determining the message (see 6.8.3)

If a BCM or BCX message replaces a BCA message in a sleep mode synchronous burst,the replaced message is sent directly in the following (non–sleep) V[0] burst.

Note1: If the auxiliary information is really required to be broadcasted depends on the implementatd customization schemes.

6.8.2 System broadcast message definition

Table 10. F28 messages from MU to SU

ACC –Bit	Message 0	Message 1	Message 2	Message 3	Message 4	Message 5	Message 6	Message 7
31	BCSeqNo	BCSeqNo	BCSeqNo	MUacces-sl(23:0)			BCM see 6.8.3	LP[illegible]
30								
29	N_{down}	ExtDuplex						
28		N_{TDD}						
27								
26								
25	Sleep-Frames							
24								
23			MUacces-sl(15:0)					
22		N_{Fr}						
21								
20								
19								
18								
17								
16								
15	MUacces-sl(31:24)	MUacces-sl(23:16)						
14								
13								
12								
11								
10								
9								
8								
7	reserved							
6	AccessAllowed							
5	SleepBurst							
4	SleepMode							
3	0	0	0	0	1	1	1	1
2	0	0	1	1	0	0	1	1
1	0	1	0	1	0	1	0	1
0	1							

Note1: Message 6 is directly acknowledged on the uplink, which is accordingly blocked for access messages. If message 6 has been sent during a sleep burst

the next message will be on V[0] with AccessAllowed = 1 to allow faster access from the SUs.

MAC Messages (BCM)

This message contains several different messages that are (normally) sent during the sleep burst. AccessAllowed is 0, only the SU that is addressed directly by its registration number is allowed to answer.
If a MAC message is sent during a sleep burst the next v–channel burst is V[0] with AccessAllowed = 1 to allow other SUs to send a CONNECT_INQ message.

Table 11. BCM messages

ACC –Bit	CONNECT_Req	STILL_ALIVE_PAGING	FIXED_GROUP_PAGING	DYNAMIC_GROUP_PAGING	
24–31	RegNum	RegNum	Fixed PAGI	Dynamic PAGI	Reserved for future use, eg. Login_Req(RAND), CONNECT_INQ(TESI), CONNECT_Req(TESI,RAND), CONNECT_Req(TESI<>0)
16–23					
15	ChannelID				
14					
13					
12					
11	VChannel				
10	0	0	0	0	
9	0	0	1	1	
8	0	1	0	1	
7	reserved				
6	AccessAllowed =0		AccessAllowed =1		AccessAllowed
5	SleepBurst				
4	SleepMode				
3	1				
2	1				
1	0				
0	1				

6.8.4 System broadcasting in sleep mode synchronous bursts

Sleep mode synchronous bursts are bursts, that are sent regardless of whether the MU is in the sleep mode or not. An SU may thus enter a sleep mode synchronized to these bursts (ie with timing $t_{slot}*N_{Fr}*SleepFrames$) and would not need to change the timing if the MU enters or leaves the sleep mode. Every

sleep mode synchronous burst carries a broadcast message on V[0]. Multiplexing the broadcast messages into these bursts is done in the following way:

1 BCS information is sent in every burst

2 A basic broadcast cycle of BCA messages comprises 3 bursts o[illegible] which messages 0–2 are sent.

Paging (BCM) and auxiliary broadcasting (BCX) information are only sent in the respective cases. BCX or BCM messages are prioritized over BCA messages, they replace BCA information that would have been send instead without changing the usual cycle of messages. It is up to the MU how to prioritize BCM and BCX messages (ie how to weigh their importance).

Note1: If BCASeqNo equals zero, the SU can assume that the MU uses a fixed known default set of BCA information. If the SU has stored this data set earlier a faster synchronization to the MU is possible.

6.8.5 System broadcasting in bursts that are not sleep mode synchronous

An MU that is not in the sleep mode maintains the broadcasting in sleep mode synchronous bursts. SUs can keep their activities accordingly. The MU may additionally transmit broadcast information in bursts other than the sleep mode synchronous bursts. This can be done to reduce the time that an SU needs to collect a full set of BCA information.

6.9 M24 messages

M24 messages are primarily used during connection establishment and disconnection.

Table 12. M24 messages from SU to MU

ACC– [illegible]	CON-NECT_INQ	DISCON_INQ	Ack	CON-NECT_Rej	STA-TUS_INFO	CHAND_INQ
[illegible]4	RegNum					tbd
23–16						
15	ConfReq	Reason		Reason	Status information about the SU	
14						
13						
12						
11						
10						
9						
8						
1–7: Message Number	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	1	1
	0	0	1	1	0	0
	0	1	0	1	0	1
0	1					

6.10 Parameter write and lookup (F16/F24 messages)

The address offsets for parameter read/write are not yet fixed.

6.10.1 Memory Access Control

This field contains functionality to extend addressing and to protect the memory access against invalid commands that may slip through the EC–message error protection (16–bit CRC).

Table 13. Memory access control fields

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Addr[illegible] O[illegible]
Memory Access Control					
Page	Used to extend addressing by using memory pages. **Note:** This address has to be used identically on all pages if memory pages are used.	R/W	16 b	0h	–
WrResAddr	write restriction address, if an address other than 0 is written to this location, only the designated address and the addresses for memory access control (this block) are enabled for writing (2–byte access).	R/W	14 b	2h	–
RO	read only, setting this bit to 1 disables RMAP write accesses except for this word	R/W	1 b	2h + 15b	–

6.10.2 Static Slave Configuration Information

Static slave configuration information is stored in non–volatile SU memory (eg EEPROM or FLASH) or is hard–wired.

Table 14. Static Slave Configuration Information fields

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Address Offset
GSI fields (General Slave Information)					
HWtype	SU hardware type, this value is used by the MU to identify the applicable memory map for the upper half of the addresses	R	8 b	0h	–
ParSetID	GSI field parameter set ID, if the SU gives a nonzero number here, the number is uniquely associated with the particular parameter set provided in the GSI fields. Ie, an MU that stores the parameter set is permitted to read only this ID and use a previously retrieved parameter set to speed up processing.	R	8 b		–
UserTraffic	Specifies which user traffic has to be provided on ACC and TCH by the MU. 0 = ACC not used TCH carries user data stream 1 = ACC carries user data stream TCH carries a–law encoded PCM 4–255 = reserved for extensions	R	8 b		–
TCHcapDwn	required nominal TCH capacity for downlink (MU–>SU), value is given in bits per 10 ms.	R	15 b		–
FixedDwn	Fixed capacity downlink connection 0 = not required, 1 = required	R	1 b		

Table 14. Static Slave Configuration Information fields (continued)

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Address Offset
[illegible]HcapUp	required nominal TCH capacity for the uplink (SU–>MU), value is given in bits per 10 ms.	R	15 b		–
FixedDwn	Fixed capacity uplink connection 0 = not required, 1 = required	R	1 b		
TCHMaxDwn-Length	Maximal TCH length the SU is able to handle in the downlink (MU–>SU)	R	9 b		–
TCHMaxU-pLength	Maximal TCH length the SU is able to handle in the uplink (SU–>MU)	R	9 b		–
MaxNFr	maximum nominal frame timing (unit: t_{slot}) (eg due to delay requirements for an audio slave or internal buffer limitations)	R	8 b		–
MinDsep	minimum duplex separation, $0 \leq$ MinDsep < 200 [T] (<245 μs) (to be able to switch between Rx and Tx)	R	8 b		–
PSI fields (Protected Slave Information)					
EQI	equipment identity, factory programmed unique serial number, only used for advanced encryption and authentication	R	64 b		?h

Note: PSI addresses can only be read in registration mode since they contain information that has to be protected for security reasons.

6.10.3 Registration Information

Table 15. Registration Information

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Address Offset
RGI (registration information, non–volatile SU storage, eg EE-PROM)			256 b		
RegNum	registration number, a non–zero number programmed during registration by the MU. RegNum is sent with the access message from SU to MU to identify which SU wants to access to the MU.	R/W	16 b	0h	–
MUaccessI	MU access identity (cf Table 6)	R/W	48 b	4h	?h
reserved	reserved for future extensions of the registration information		160 b	Ch	?h
RGIx (registration information, non–volatile SU storage)			(N–1)*256 b		
reserved	reserved for N–1 more registration access data sets	R/W	(N–1)*256 b	40h	?h

Note: The RGI fields are only writable in registration mode. Requesting an authentication code from the SU is done using the command CAUTH.

6.10.4 MU/Connection Configuration Information

Table 16. MU/Connection Configuration Information

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Address Offset
GMI (General MU Information)					
N_{Fr}	(cf Table 9)	R/W	7 b		–
N_{down}	(cf Table 9)	R/W	4 b		–
N_{TDD}	(cf Table 9)	R/W	3 b		–
ExtDuplex	(cf Table 9)	R/W	1 b		–
SleepFrames	(cf Table 9)	R/W	10 b		–
SCI (Session Configuration Information)					
DPAGI	dynamic paging group identity (0..65535), a dynamic group paging code, used to wake up the SU if dynamic group paging is used	R/W	16 b		–
SleepMode-Conf	Sleep mode configuration. tbd	R/W	8 b		–
SSI (Slave Status Information)					
Status	Status flags of the SU: 0x01: ALLOW_DISCONNECT = The SU is willing to be disconnected (eg. it has no user traffic to be sent to the MU). The actual DISCONNECT decision is done in the MU.	R	16 b		
CI (Connection Information) (writing directly affects the parameter)					
TCHarq	Use of send&wait ARQ on TCH data 0 = not used, 1 = used	R/W	1 b		
EncEna	encryption enable, 0: encryption is off 1: encryption is active	R/W	1 b		–
UserTrafficEna	0 = only LPRF internal signaling allowed, 1 = User traffic may be exchanged as negotiated	R/W	1 b		–
MaxTCH-lengthDwn	maximum permissible length of TCH in bytes for the downlink (MU–>SU)	R/W	9 b		–
MaxTCHleng-thUp	maximum permissible length of TCH in bytes for the uplink (SU–>MU)	R/W	9 b		–
CHI (Channel Information) (activated as a data set using the CHAND command, cf sect. 6.10.5)					
VChannel	0 = f–channel 1 = v–channel	R/W	1 b		?h
ChanelID	TDMA channel ID	R/W	4 b		?h

Table 16. MU/Connection Configuration Information (continued)

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Address Offset
AllocDn	Downlink slot allocation mask	R/W	128 b		?h
AllocUp	Uplink slot allocation mask	R/W	128 b		?h
AllocExt	Extension flags to slot allocation masks	R/W	128 b		?h

For channel handover, the MU programs new parameters into the CHI field and use the CHAND command to make the SU switching to the new parameter set.

If the carrier needs to be changed special procedures preferably apply (see MAC procedures definition)

6.10.5 SU Commanding

Table 17. Slave memory map structure

Field Name	Description	R/W	Effective Size	F16 Address Offset	F24 Address Offset
COM (Slave Commanding)			512 b		
OpCode	write accesses command SUs to perform the indicated action. Some commands require additional parameters as specified in the field(s) ComParX.	R/W	8 b	0h	?h
ComPar1	command parameter 1	R/W	8 b	1h	?h
ComPar2	command parameter 2	R/W	16 b	2h	?h
reserved	for 14 more parameters	R/W	224 b	4h	?h
COMret1	command return value 1	R	15 b	20h	?h
ComStat	command status, 0: last command completed 1: command is currently being processed	R	1 b	21h+7b	?h
COMret2	command return value 2	R	16 b	22h	?h
reserved	for 14 more return values	R	224 b	24h	?h

Table 18 specifies the possible commands. If not mentioned otherwise, a single parameter has to be placed in the field COMpar1 and a single return value is placed in the COMret1 field.

Table 18. Command definition

Code	Mnemonic	Short Description (SU is commanded to ...)	Parameter(s) (ComPar1 if not stated differently)	Return Value(s) (ComRet1 if not stated differently)
0	NOP	no operation	–	–
	DISCON_Req	terminate the active connection to the MU	Reason (8 b)	–

Table 18. Command definition (continued)

	CAUTH	compute authentication code	RandSeed (128 b)	Code (127 b)
	CENCR	compute encryption key	RandSeed (128 b)	–
	CHAND	perform channel hand-over	–	–

6.11 Basic access procedures

The basic acces procedures are identical to |1| with minor modifications due to the extended slot length. Additionally procedures are specified which can be used by SUs that are running in a synchronized sleep mode to an MU.

6.12 Connection establishment

The SU sends a connection inquiry (CONNECT_INQ) in the uplink of a broadcast downlink on V[0] with the broadcast bit AccessAllowed=1. The MU answers with a connection request (CONNECT_REQ) which contains the channel number to be used for the connection to the SU.

An MU initiated connection starts as well with a connection request. In any case, the SU answers the CONNECT_INQ with an acknowledge (M28 message Ack). After that both parties change to the designated v–channel and start communication (on the ACC) mainly with F16/F24 messaging.

User traffic has to be enabled (allowed) separately by the MU after the channel is established.

In case of timeouts on the SU side (eg sue to collisions) the SU can retry or revert to the basic access procedures as specified for initial access.

6.13 Connection release

When the connection is not needed anymore (eg. there is no more user traffic to exchange between MU and SU) the connection is released by the MU with sending a DISCON_Req message to the SU.

In case that there is distortion so that the MU doesn't get the expected response from the SU the MU may disconnect the SU simply by omitting sending bursts for this channel. If the SU has not received a burst with the correct channel number for a preprogrammed time it will disconnect itself (see also 'sleep mode timeout').

6.14 Group paging

During sleep mode synchronous burst the MU is able to send group paging messages. The purpose of this messages is to wake up a certain group of SUs

(eg. those that need to handle incoming calls) faster. Fixed group paging codes are foreseen as well as group paging codes that are dynamically allocated to SUs.

6.15 Sleep mode timeout

If an SU is communicating with an MU it maintains a timer which is restarted with every burst that is received on its channel. Expiration of the timer leads to immediate change into the SU sleep mode to save power. This watchdog functionality has been included to avoid that SUs stay active due to channel distortion or errors in the MU implementation. The resulting power consumption would empty the battery of power critical devices very fast.

6.16 MAC procedures messages overview

This section summarizes messages that are used by MAC procedures. The remaining messaging is done using RMAP accesses and RMAP commands.

6.16.1 Messages from MU to SU

Table 19. LPRF MU messages

Name	Format	Used Chan-nel	Sleep Burst	EC/ED	Description
NOP	F16	≠ v[0]	No	ED	No Operation. (Used for testing/debugging) Contents: –
CONNECT_Req	M28 Msg. 7	v[0]	X	ED	Is sent by MU to connect a certain SU. Contents: – RegNum – VChannel – ChannelID
STILL_ALIVE_PAGING	M28 Msg. 7	v[0]	X	ED	Is used to determine if a certain SU is still listening. Contents: – Regnum
FIXED_GROUP_PAGING	M28 Msg. 7	v[0]	Yes	ED	Is used to awake a group of SUs determined by their fixed group address. Contents: – Fixed PAGI
DYNAMIC_GROUP_PAGING	M28 Msg. 7	v[0]	Yes	ED	Is used to awake a group of SUs determined by their fixed group address. Contents: – Dynamic PAGI

Table 19. LPRF MU messages (continued)

Name	Format	Used Chan-nel	Sleep Burst	EC/ED	Description
CONNECT_INQ_Rej	F24	v[0]	No	ED	MU rejects a CONNECT_INQ from the SU. Contents: – Regnum – Reason: 1) NO_CHANNEL_AVAILABLE: all v–channels are currently in use 2) tbd
DISCON_Req	F16	≠ v[0]	No	EC	The MU disconnects the SU. Contents: –
CHAND	F16	≠ v[0]	No	EC	MU initiates a channel handover. Before the MU has written the channel parameters via RMAP. Contents: –
CAUTH		≠ v[0]	No	EC	SU shall compute the authentication value. Before the MU has written the CAUTH parameters via RMAP. Contents: –
CENCR	?		No		

Note: X means any channel

6.16.2 Messages from SU to MU

Table 20. LPRF SU messages

Name	Format	Used Chan-nel	EC/ED	Description
CONNECT_INQ	F24SU	v[0]	ED	CONNECT_INQ: access message for initial connection establishment. Contents: – RegNum (cf NO TAG) – Configuration flag (SU requests default parameters) ConfReq = 1 –> Configuration required (eg defaults for f–channel) ConfReq = 0 –> no configuration required
DISCON_INQ	F24SU	≠ v[0]	EC	DISCON_REQ: connection release inquiry. Contents: – Reason: 0: no reason (this is probably an error condition) 1: power down 2: no traffic (the SU continues listening to channel 0 and can be paged)
Ack	F24SU	v[0]	ED	Ack: Respond to a 'STILL_ALIVE_PAGING' or 'CONNECT' from the MU. Contents: –

6.17 Application Broadcasting (MU–>SU)

Application level broadcasting is done on V[0] (see above). The MU informs sleeping SUs about upcoming broadcast traffic such that they can wake up to receive the broadcast messages by using the BCupdate flag of the system broadcast messages.

Typical applications for user level broadcasting are ringing indication, battery status and field strength update, etc.

6.18 Major air interface parameters

Table 21. Air interface key parameters

Parameter	value	Comment
Radio approach	frequency hopping	compliant to FCC and ETSI regulations
Multiplexing	FDM/TDM	Time division multiplexing (TDM) between SUs connecting to a single MU, frequency division multiplexing (FDM) between MUs (users).
TDMA slots	16 + 16	explicit TDMA slot numbering in bursts 16 for f–channels + 16 for v–channels (multiplexed into a single physical slot within the frame)

Table 21. Air interface key parameters (continued)

Duplexing	TDD	duplex spacing programmable, uplink follows respective downlink
Burst length	128 .. 4240 bits	variable with programmable maximum
Slot length (t_{slot})	10/13 ms	
Frame length	up to 97 ms	programmable in multiples of t_{slot}
Frame timing		alignable to cellular timing
Sleep modes		exist for MU and SU, aligned to cellular system
Max. single channel capacity (SU<–>MU)	$\geq$ 64 kbit/s	Variable within a wide range and depending on frame and burst lengths
Modulation type	CPFSK	nominal modulation index 0.32 (GFSK)
Sensitivity	–76 dBm	@ Bit Error Rate 0.001
Req. signal strength for reference BER	–70 dBm	reference BER = 0.00001
Reference oscillator	13 MHz, 16.8 MHz, 18 MHz, 19.2 MHz or 19.44 MHz	
Reference oscillator stability	30 ppm	no AFC or TCVCXO required due to loose specification
Air bit rate	812.5 kbit/s	
Frequency band	2400–2497 MHz	ISM band, pure FSK fulfils out of band power requirements with 1 channel guard frequency at the band edges
Number of carriers	23..79	depending on country
Carrier frequencies	2402+N*1 MHz	
Carrier spacing	1 MHz	
Synchronization support in the burst	32 bit preamble 16 bit unique word	capable of coping with time slips caused by changing the cellular time slot

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NOKIA

Radio system, compatible with cellular systems

Draft

Status:	Draft	v. 0.0+	27 Nov 97
Doc. number:			
Author:	Olaf J. Joeressen		
Function:	R&D Center Germany		

Pathname: /users/joeresse/desktop/NewSystem.nmr

Change History:

0.0	14 Nov 97	Olaf J. Joeressen	Working	(No comment)

Contents:

1 Intro

In the described radio system, timing is adjusted such that a fixed relationship to the frame timing of different cellular systems is achieved. By ommitting transmissions, interference and type approval problems due to concurrent activities (especially transmissions) of both systes are conquered.

In this document the timing parameters of GSM and D–AMPS/PDC are considered for the derivation of parameters. However, other systems could be taken into account as well.

Note: Since the air interface timing of PDC and D–AMPS is indentical as far as is relevant to this document, we use the term D–AMPS only below, although PDC is within scope as well.

2 Choice of frame timing

To keep a fixed relationship to the cellular frame timings, that makes it possible to avoid concurrent transmissions in a simple way and to integrate both systems easily, the chosen frame timing has to be a fraction of the frame timing of all reference systems.

For GSM (60/13 ms frame timing) and D–AMPS (20ms frame timing) possible frame timings have to satisfy:

$t_{Fr} = 60/13/N_{GSM} = 20/N_{D-AMPS}$

or

$t_{Fr/20} = 3/13/N_{GSM} = 1/N_{D-AMPS}$

with N_{GSM} denoting the number of frames per GSM frame and N_{D-AMPS} the number of frames per D–AMPS frame.

Since 3 and 13 are prime numbers, the possible choices for N_{GSM} and N_{D-AMPS} are:

$N_{GSM} = 3 * K$ and $N_{D-AMPS} = 13 * K$

with K being a natural number.

To reduce packet overhead in the radio system, chosing a small value for K is preferable. To obtain additionally an even number of frames per cellular frame, which permits putting pairs of uplink/downlink activities into the callular frame, K=2 is the best choice. Thus we obtain $N_{GSM} = 6$ and $N_{D-AMPS} = 26$ and accordingly $T_{Fr} = 10/13$ ms.

2.1 GSM case

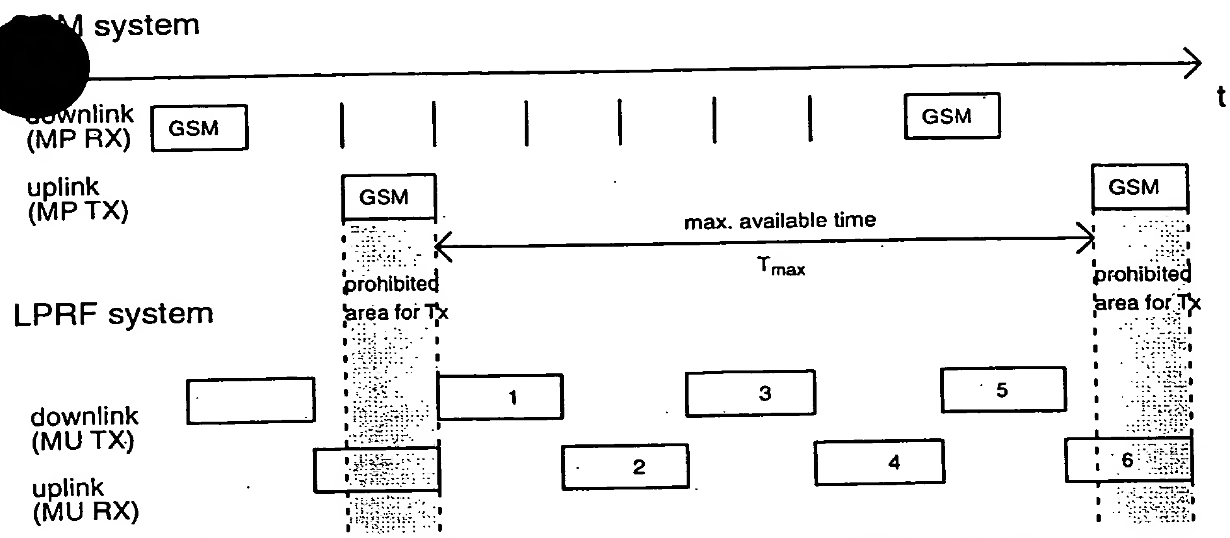


Figure 1. GSM timing example for single slot GSM connection

Figure 1 shows an example for GSM and single slot GSM transmit. For the subsystem alternating uplin and downlink frames are assumed. As is visible, transmissions during GSM Tx can be avoided by aligning the timing to the GSM transmissions. If it is possible to receive during GSM transmit, the full capacity is available. otherwise 2/3 of the capacity of the uplink remains, while the downlink is still completely available. Frame 5 could for example still carry broadcast information.

For HSCSD 3+1 only one GSM transmit slot is used, thus the same capacity is achieved.

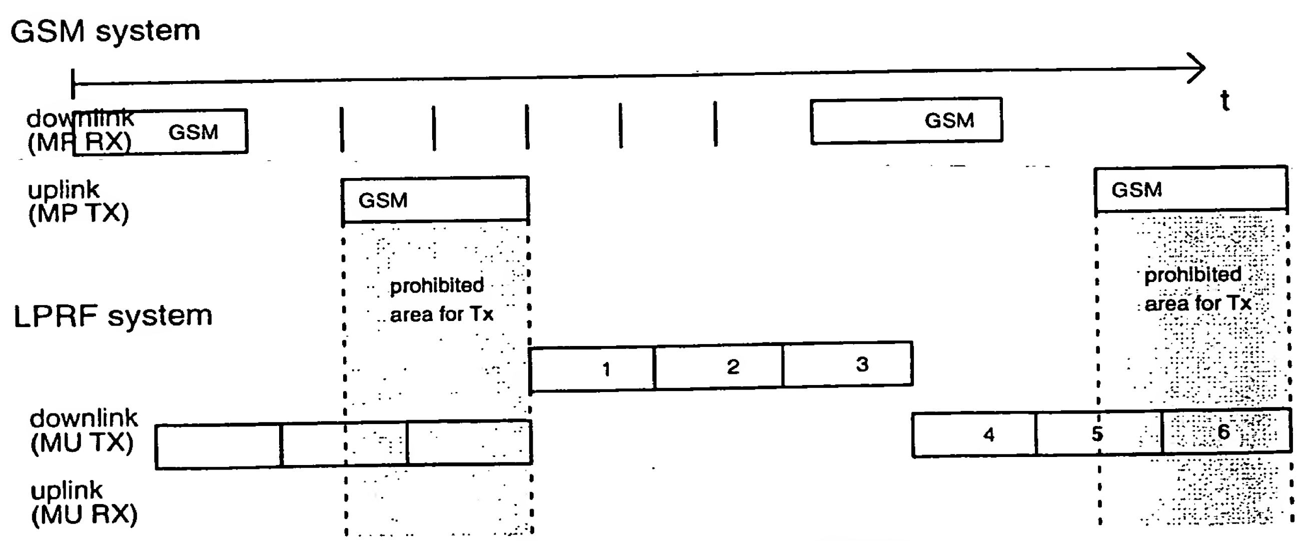


Figure 2. GSM timing example for HSCSD 2+2

For HSCSD 2+2, two subsequent GSM slots are used for transmission. Thus the timing according Figure 1 would lead to restrictions even if reception during GSM transmit is possible. By chosing a different duplex timing for connections, the full capacity can be obtained again.

If no reception is possible during GSM transmit, 2/3 of the total capacity remains.

In any case, fixed delay connections (eg audio) can use every pair of frames with a delay equaling to the GSM frame timing. If all three pairs can be used, at least the timing according to Figure 1 permits fixed rate connections with 1/3 and 2/3 of the GSM frame timing are possible.

2.2 PDC/D–AMPS case

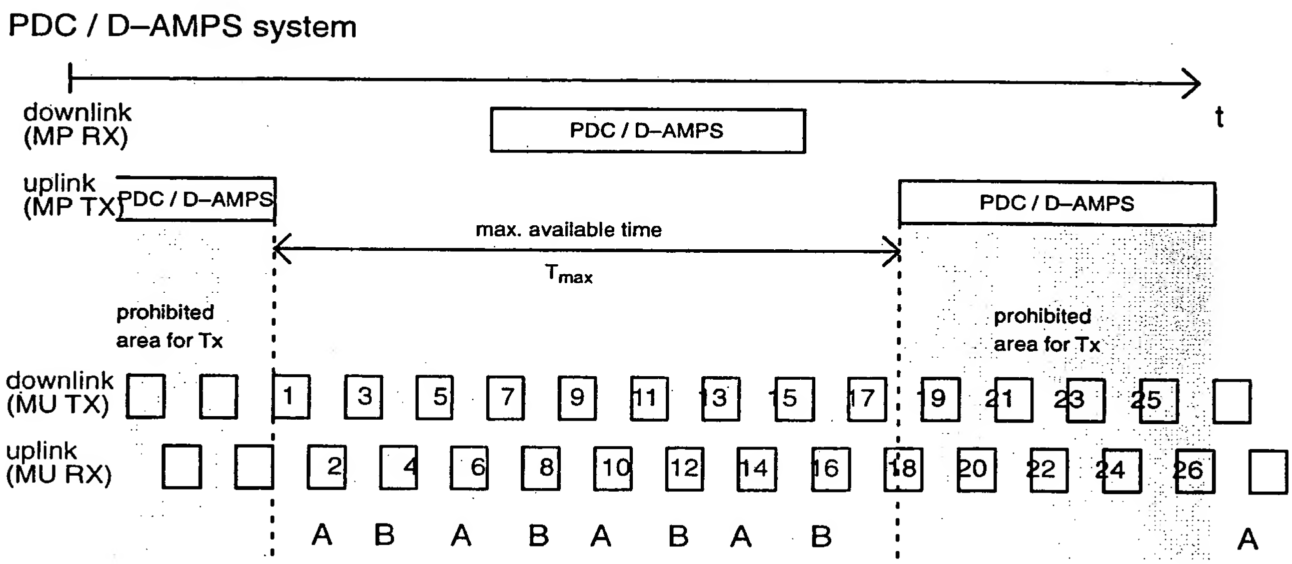


Figure 3. PDC/D–AMPS timing example

Figure 3 shows a timing example for PDC/D–AMPS. Clearly four downlink slots are blocked even if reception during cellular transmit is possible. The frame pairs which are nembered A and B respectively would form two connections with similar capacity as one pair of frames within the GSM cellular frame. However, the involved worst case delay would be 14*10/13 = 10.77 ms.

Obviously, PDC benefits even more from using special patterns of frame usage that puts uplink frames into the period of cellular transmissions. In the simplest case, this could be done by using frames 1–13 for transmission and 14–26 for reception. Such a usage pattern would obviously lead to larger delay for individual connections.

2.3 Frame usage patterns

As has maybe become clear for the discussed timing scenarios above, the best capacity and performance can be obtained if the duplex timing and allocation of uplink and downlink to frames are configurable.

This could be done by broadcasting a default duplex timing for access bursts and configuring the actual usage of frames for every actual connection.

Methods to rearrange the usage pattern in the case of cellular slot changes and changing timing advnace need to be implemented.

2.4 Timing adjustments

The system should tolerate timing adjustments resulting from changing timing advance in the cellular system and/or slot changes.

3 Frequency hopping

If the slots are counted without caring about the blocked periods, the system can perform a frequency hopping based on the slot timing (in the example 1300 hops/s). For connections, the missing transmissions can then be handled as if the frequency hopper has hit in regular intervals interference that make communication impossible. A well designed frequency hopping system could thus be adapted to the proposed timing without major changes in air interface management.

However, frame usage patterns would provide better efficiency compared to a brute force frequency hopping overlay !

4 Implementation into current LPRF incl. frequency hopping

4.1 General

It seem useless to reinvent the wheel, thus the basic access schemes could be taken from the MC–link proposal. Thus instantaneous networking could be done by sending inquiry trains and paging could be done either as we are considering it or using paging trains as used in MC–link.

The assumption here is that both is supported to provide fast access to synchronized devices with different paging modes (group paging, etc) as well as paging trains as a fallback solution for devices that lost contact and did not manage to re–contact again.

4.1.1 Selected valuable LPRF features missing in MC–link

- paging and sleep modes as in LRPF lead to better power efficiency.
  SU power consumption is reduced during sleep mode since since only the beacon needs to be received instead of requiring scanning for paging/inquiry trains in regular intervals.
- timing alignment
- registration (at least as an option) to handle security issues. If we rely on higher layer access handling (eg using passwords) we may rule out devices without UI (headsets etc.).

4.1.2 Selected valuable MC–link features missing in LPRF

- frequency hopping + access schemes –> simplified radio resource management
- ad hoc networking without registration
- a common time base for all systems will ease network–to–network communication
- fixed frame timing simplifies multi–frame counting
-

4.1.3 Problems/Open Items with frequency hopping approach

- full range of carriers may prevent global usage (type approval)
- how to configure slave unit over the air to local restrictions.
  In LPRF the phone was supposed to know restrictions and could broadcast these, while the access scheme of MC–link complicates this since the MU is assumed to use 32 carriers of the USA/Europe band during inquiry.

4.1.4 Selected commonalities

- fast ARQ with HW support

4.2 Assumption for the discussion below

The following assumptions are made:

- 1300 slots/s
- LPRF header + 16 bit TCH CRC

4.3 Timing

4.3.1 Slot timing and capacity

- 1300 hops/s and 10/13 ms (=0.769 ms) slot duration accordingly, leading to 6 slots for a GSM frame and 26 slots for a PDC frame
- it is assumed the a single slot can carry 40 bytes of data which gives 16 kbit/s capacity for PDC frame timing and slightly more than 69.33 kbit/s for GSM frame timing. Thus a 64 kbit/s audio connection can be carried in one slot in the GSM case and 4 slots in the PDC case. With the current LPRF header + TCH CRC (144 bit), this is possible even if we keep 812.5 kbit/s as the air bit rate (with 198 µs guard time remaining).

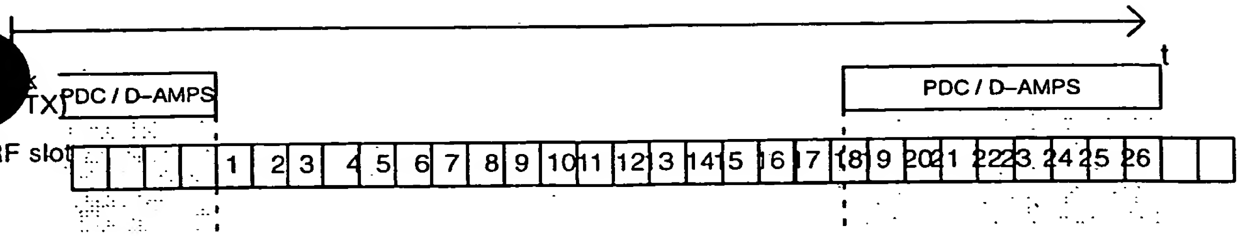
Table 1. Slot capacities

Scenario	LPRF header @ 812.5 ksym/s	LPRF header @ 1 Msym/s		
Single slot				
Traffic per burst [byte]	40			
Capacity @ 2–slot frame timing	208 kbit/s			
Capacity @ GSM frame timing	69.33 kbit/s			
Capacity @ 20ms frame timing	16 kbit/s			
Guard time [µs]	198	305		
Double slot				
Traffic per burst [byte]	118	136		
Capacity @ 3–slot frame timing	409 kbit/s	471 kbit/s		
Capacity @ 4–slot frame timing	306 kbit/s	353 kbit/s		
Capacity @ GSM frame timing	204.5 kbit/s	235.7 kbit/s		
Capacity @ 20ms frame timing	47.2 kbit/s	54.4 kbit/s		
Double slot + 40 byte (uplink without traffic)				
Traffic per burst [byte]	158	176		
Capacity @ 3–slot frame timing	547 kbit/s	610 kbit/s		
Capacity @ GSM frame timing	273 kbit/s	305 kbit/s		
Capacity @ 20ms frame timing	63.2 kbit/s	70.4 kbit/s		
Triple slot				
Traffic per burst [byte]	196	232		
Capacity @ 4–slot frame timing	509 kbit/s	603 kbit/s		
Capacity @ GSM frame timing	339 kbit/s	402 kbit/s		
Capacity @ 20ms frame timing	78.4 kbit/s	92.8 kbit/s		
Triple slot + 40 byte (uplink without traffic)				
Traffic per burst [byte]	236	272		
Capacity @ 4–slot frame timing	613 kbit/s	707 kbit/s		
Capacity @ GSM frame timing	409 kbit/s	471 kbit/s		
Capacity @ 20ms frame timing	94.4 kbit/s	108.8 kbit/s		

4.3.2 Slot allocation to channels

For every channel, time slots can be allocated arbitrarily in a sequence of N_{rep} slots which determines the length of a multi frame for which slot allocations repeat. For v–channels, slots can be allocated to multiple connections and are dynamically arbitrated using the channel identity as described for v–channels in the LPRF specifications.

PDC / D–AMPS system



F[0] D U – – – D U – – – D U – – – D U – – – – – – – – – –

V[0],V[2] – – D – U –

V[1] – – D D U – – D D U – – D D U – – – – – – – – – – – –

D = downlink slot
U = uplink slot
– = not allocated for this connection

Figure 4. PDC/D–AMPS timing example

Figure 4 gives and example how slots could be allocated at a certain time for the PDC phone. F[0] carried a 64 kbit/s audio stream and is allocated such that the delay is minimized (it is 11 slots = 8.46 ms). V[0] is basically the beacon and the allocated time slots are sharde with a low rate v–channel (V[2]) as well as a high rate v–channel (V[1]) which has as well assymetric capacity since twice as many downlink slots are allocated as uplink slots. Of course double slots carry only a single frame to optimize capacity (at 812.5 kbit/s the downlink capacity for V[1] would be 141 kbit/s).

Clearly, power consumption can be optimized by reducing the number of required receive activities for V[0] and V[2] while at the same time providing high throughput for other connections.

However, with the exception of V[0], the allocations are not broadcasted but negotiated. At least for V[0] the length of the allocation table need to be broadcasted. Furthermore, broadcasting of the multi–frame start is needed to synchronize correctly.

4.3.3 Handling of timing changes (TA + timing slips)

4.4 Required system broadcast information

Since initial contacts will usually be handled in the way as proposed for MC–link, no broadcast information is required to connect to a master that sends a paging or inquiry train.

System broadcast information is only required if the allocation of slots to connections can vary even for the beacon transmissions on V[0], which is actually assumed here.

In this case the following information is needed:

- the length of the allocation sequence N_{rep}
- the position of the V[0] downlink (this may be always 0 !?)
- the position of the V[0] uplink (in slots relative to downlink)
- the MUs public identity

Futhermore it might be useful to broadcast

- sleep mode timing
- worst case timing slip (!?)
- additional information related to hopping
- sleep mode flags
- broadcast sequence number
- country flags (Japan !?)

5 Required change to make LPRF a frequency hopping system according to the proposed approach

Advantages

5.2 Disadvantages

5.3 Additions/Changes

- to facilitate easy slot change timing slip, the MU should broadcast a timing offset relative to a fixed hopping sequence such that the frequency after a timing slip is predictable.
- support slot usage patterns and start flag for pattern to allocated capacity to links and enable low power modes
- at least v–channel pattern needs to be broadcasted
- add radio resource management and access scheme to support frequency hopping
- use different channel spacing + modulation scheme
- upgrade to 1Mbit/s (?) if neccessary

5.4 Things that can be removed

- remove unneccessary timing parameter broadcasts for frame timing, max. timing slip
- remove carrier change broadcast
- remove radio resource management part needed for single carrier system, eg RSSI based carrier selection, beacon transmission (?), etc.
-

5.5 Nice to have

- FEC options for traffic transmission
- block protection option in TCH
- ACC capacity extension on demand
- courtesy mode for some services of master units to support service without registration
- support for instantaneous network setup is probably needed

[] 1

The present invention includes any novel feature or combination of features disclosed herein either explicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed.

In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.